Optical local area networking using CWDM

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ABSTRACT

This paper describes the current status of Coarse Wavelength Division Multiplexing (CWDM), and then progresses to discuss how it may evolve in networking applications in the future. As WDM can enhance not only transmission but also networking systems, the paper reports a potentially low cost WDM based access node architecture, particularly suited for routing optical data packets on nanosecond timescales. The scheme is cascadable and involves the use of a simple semiconductor optical amplifier (SAO) based add-drop switch. Preliminary results concerning the operation of the add-drop switches under multi-wavelength operation are reported.

1. INTRODUCTION

The data capacity needed by PC users[1] continues to show an upward trend. A series of reasons can be attributed to this phenomenon, a key one being the growth in the clock speed of processors. This growth is sufficient, according to Moore's Law, that clock speeds in personal computers can be expected to reach 10Gb/s within the next few years. In addition, the increase of commercial and entertainment applications which use large communication bandwidths, particularly those involving interactive audio and video links, has placed extra burdens on standard infrastructure. The increase in bandwidth has been felt not only in the core network where single mode optical fibre dominates, but also in the access and local area networks (LANs) where there is a continuing evolution from copper-based links to higher bandwidth transmission media such as broadband wireless and optical fibre. As the core network has had large bandwidth requirements for some years, wavelength division multiplexing has been widely introduced and developed to a level that meets many requirements. However WDM has not had similar penetration into local and computer area networks. Here there remains a preponderance of multi-mode fibre (MMF), because it is easier to handle during installation in comparison with single mode fibre (SMF), and there remains a large base of legacy fibre. The need for increased bandwidth thus has necessitated communication networks able to work on both optical fibre types.

This paper will therefore review the use of low cost WDM for short haul networking applications. Such networks are dominated by communication standards to allow inter-working between different manufacturers of components

and equipment, and hence the paper will provide a short introduction to these standards, highlighting both the IEEE Gigabit Ethernet and the International Telecommunications Union (ITU), in section two.

The continuing growth in bandwidth requirements has led to renewed interest in the use of low cost optics, not only to transmit signals over short links but also to be used in the networking of sites. In this paper, therefore we proceed in section 3, to discuss how CWDM communications can be configured not only to enhance the transmission achievable in a given link, but also to ease networking and packet routing of signals. An architecture is outlined making use of a simple and potentially low cost active add-drop multiplexer, initial results of initial WDM routing being reported to illustrate the potential of the approach. This switch is chosen because it is compact, can provide high extinction ratio, switch in nanosecond timescales, provide on-chip gain and provide sufficient spectral bandwidths for CWDM applications. Initial results are reported concerning the performance of the switch under multiwavelength operation.

2. REVIEW OF CWDM SYSTEMS FOR SHORT HAUL TRANSMISSION LINKS

WDM has played a key role in telecommunications for many years, and matured sufficiently that Dense Wavelength Division Multiplexed (DWDM) systems have been widely demonstrated at aggregate bit rates of up to and beyond 1 Tb/s along a single fibre using multiple wavelengths carrying data at rates of either 10Gb/s[2] or 40Gb/s[3]. By way of example, the International Telecommunication Union (ITU) has specified the wavelengths of operation for DWDM on a very precise grid of 80 wavelengths (ITU-T G.692) in the 1.5μm window. This requires temperature and current control of the wavelength of distributed feedback (DFB) lasers, used in the system, to levels in the region of mK and mA.Precise control also assumes optical feedback techniques, set by both laser characterisation and typically a photo-detector with a strong wavelength slope, to lock the wavelengths to within ~5GHz of the specific wavelength of use.

Despite the importance of these systems for high performance use, there remains much interest in lower cost shorter haul links for use in the access and metro areas of the telecommunication network. Here the cost of the transmitters is a more critical issue than for long distance communications, and CWDM systems using uncooled components are preferred involving fewer channels. As a result, the ITU has defined a grid of 18 CWDM channels[4] in draft G694.2, each 20nm wide with wavelength centres from 1270nm to 1610nm. In the centre of the band, at ~1400 nm is the water absorption peak which increases the fibre loss significantly. Installed fibres will have an undefined water absorption but new fibres have been published[5], which suppress this peak and allow the full grid of wavelengths to be used in new fibre systems. Using this new fibre, Sumitomo have demonstrated[6] transmission of 160 Gb/s using 16 channels over a 12km link. The loss in the fibre water peak is <0.3dB at 1400nm and the dispersion is designed to be –12ps/nm/km at 1300nm and 4.4 ps/nm/km at 1550nm. This gives a negative transmission penalty after 12km at 1300nm and less than 1.0 dB transmission penalty due to dispersion at 1550nm, rising to 1.7dB at 1570nm.

The history of CWDM in LANs is also long, WDM systems having been widely investigated in the early 1980s[7] and also proposed for use in a LAN[8]. Interest in the technology has not diminished with time however, and following a proposal by Hewlett Packard, CWDM was recently adopted[9] to extend the transmission distance for data communication at 10Gb/s in the IEEE Ethernet standard[10] committee. Initially systems using both short wavelength surface-emitting lasers[11] and those with 1.3μm wavelength devices were considered before selection of 1.3μm systems was finalised. This standard has now been fully developed and was formally issued by the IEEE standard in November 02. The CWDM version is designated 10BASE-LX4 and the transmission distances that can be achieved are shown below in Table 1.

Description	62.5µm MMF	50µm MMF		10µm SMF	Units
Modal bandwidth as measured at 1300nm (minimum, overfilled launch)	500	400	500		MHz.km
Link power budget	7.5	7.5	7.5	8.2	dB
Operating distance available	300	240	300	10,000	m

Table 1. Specification of 10 BASE-LX4 CWDM Links as adopted by the IEEE 802.3ae standard.

A feature of the standard is that two of the multimode fibre options meet the crucial short reach distance of 300m, which is one of the building standards for fibre cable plant[12]. Multi-mode fibre is widely installed within buildings and a 10Gb/s optical standard for multi-mode fibre is highly important commercially, since it allows existing cable plant to continue to be used despite the increased data rates[13].

It should be noted that the limit of operating distance in MMF is due to the fibre modal bandwidth. Such limits are similar to those found during the development of GbE standard where it was observed that the established method[14] of measuring the fibre modal bandwidth did not give the worst case bandwidth value, for some pre-installed fibres[15]. The lower observed bandwidths (bandwidth collapse) are primarily due to a perturbation in the index profile in the centre of some fibres. Injection of light into the fibre core centre, say from a narrow spot laser diode, results in an anomalously low link bandwidth. One method of rectifying the modal bandwidth of these types of fibre, and hence achieving the predicted link performance, is to prevent the launched light into the fibre from exciting all the modes[16] in the fibre so that the differential path length is not so broad. The multi-mode version of CWDM specified in 10GbE uses an offset launch patchcord to achieve this restricted launch[17,18].

Parameter	Value	Units
Signalling rate	3.125[1]	GBd
Wavelengths	1269.0 - 1282.4 1293.5 - 1306.9 1318.0 - 1331.4 1342.5 - 1355.9	nm
Average launch power 4 wavelengths	5.5	dBm
Average launch power per wavelength	-0.5	dBm
Optical modulation amplitude per wavelength	211 MMF, 237 SMF[2]	µW
Extinction ratio (min.)	3.5	dB

Table 2: Key specifications for a 10 GbE CWDM system.

[1] This increased data rate is encoded to ease the electronic design
[2] The MMF version includes 0.5dB loss for the offset launch optical patchcord

The key optical characteristics of the 10 GbE CWDM system are shown in Table 2, a schematic diagram being provided in Figure 1. The transmitter wavelengths are set to be within a window of 13.4-13.6nm and between each window is a guard band of 11.1nm. All of the four wavelengths are in the 1.3μm low dispersion and moderate loss fibre window. The purpose of this specification is to transmit 10GbE using a lower signalling rate and therefore the critical factors are the total combined signals. The interfaces Test Point 2 and Test Point 3 are the same as the single wavelength version, on the output of the multiplexer and the input to the de-multiplexer. Therefore any product which meets the standard has an internal wavelength multiplexer and demultiplexer to meet the interface specification.

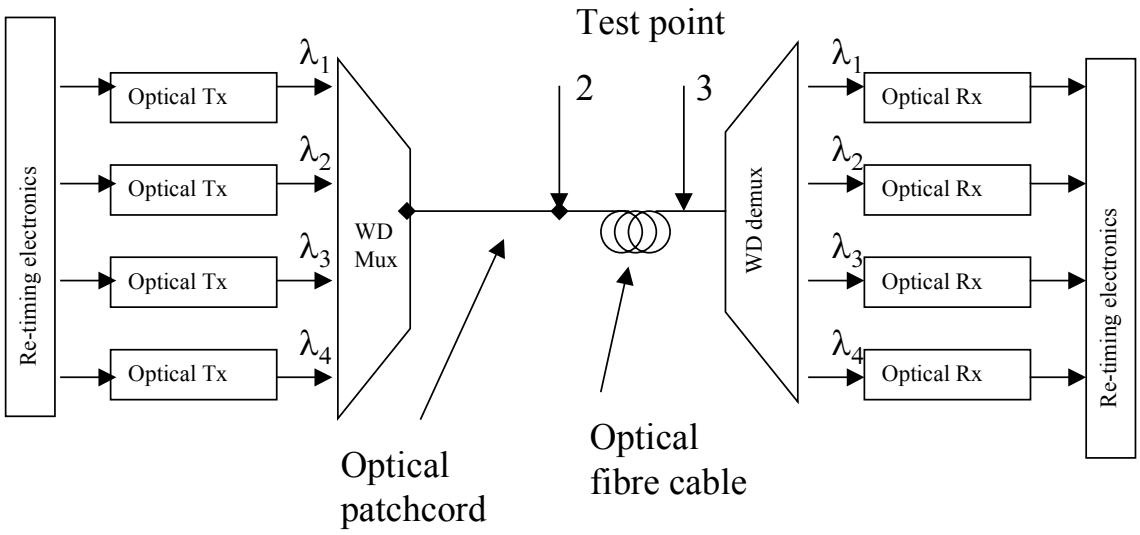


Figure 1: Simplified interface for the 10GbE CWDM standard

The promise of increased transmission capacity through the use of CWDM, avoiding the higher costs of DWDM, has received considerable interest from many companies. It is estimated that packaging methods and control issues lead to estimates of a cost reduction of 4-5 times[19] for a CWDM over DWDM, although specific values vary[20], with a ~4 times reduction in footprint. There has been considerable commercial interest in designs and products for CWDM, with the focus of reducing the cost, power requirements and size of the transceiver sub-systems[21].

Products are available for CWDM from many companies and the application has now broadened from the 10GbE[22] where the mux-demux is integrated within the transceiver to more general use. CDWM is now frequently implemented with a separate mux-demux unit[23] [24] [25], so that increased capacity can be readily introduced when needed, simply by adding lasers or detectors at new wavelengths. This approach gives the option of a large future capacity but with a lower initial cost. An overview of the commercial trends in CWDM for datacommunications is available[26].

3. WDM NETWORKING

As network bandwidth requirements have increased and transmission costs have dropped, the relative cost and complexity of networking sub-systems has grown. As a result, the networking bottleneck has shifted from data transmission to switching and routing. Optical switching has been investigated to address these issues, though to date has often been studied with telecommunications applications in mind. Packet switched networks have been investigated[27,28,29], where switching speeds must be ~ns and the traffic is highly bursty in nature. However LAN networks need a different, lower cost approach. The main criterion for an optical large capacity node in a LAN is the low latency, and optical buffering and optical signal processing are avoided to ensure lowest cost. Using WDM

in a different manner from the traditional one channel of information mapping onto one wavelength gives more flexibility with the greater throughput. An optical byte wide bus[30] and bit parallel WDM[31] have been previously proposed and in these approaches bits (or bytes) are launched simultaneously on different wavelengths. For clarity this is referred to as wavelength striping and is illustrated in figure 2, the wavelengths representing the different bits (or bytes) are transmitted simultaneously along the same fibre and switch channel.

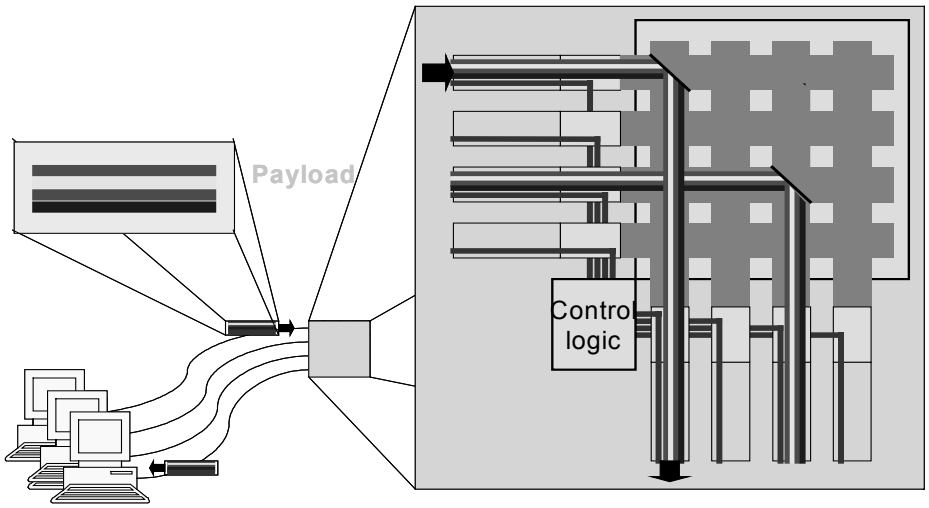


Figure 2: Schematic diagram showing the use of the different wavelengths in routing the data.

At Cambridge we have sought to develop a new design strategy for switched data networks which uses established electronic technology to handle the more complex switching and buffering functions, with the use of low cost CWDM optoelectronic components that enhance access node capacity. This ensures more efficient packet throughput across the network using this WDM topology than conventional schemes. The use of a single lower speed WDM channel at 1300 nm to carry the control functions for the network is a key feature of the scheme. High speed channels are used to carry the data, allowing the most complex electronic signal processing to use slower speed and lower cost circuitry to control the network thus achieving reduced component count and power consumption. Using current low cost, low footprint uncooled optical transceiver technology, currently being developed for point to point synchronous data transmission, for the high capacity data transfer, removes the intelligence in the optical domain. The approach has the significant advantage of allowing operation in an asynchronous network and is well suited to packet routing at highly scaleable bit rates.

A number of access nodes are linked on an optical ring by means of multiple wavelength channels in the proposed network, as shown in the schematic diagram figure 3. The physical implementation can be either a star, if the optical LAN is collapsed to the central hub, or is expanded it becomes a bus network. All routing information is transmitted at the control wavelength to avoid the necessity for complex high speed header processing. The data rate of the control channel is sufficiently high to manage the packet transport, but within the limits of current electronic signal processing. The second wavelength band at 1500 nm is available for multiple data channels which may be implemented in CWDM for high aggregate data capacity (e.g. n x 10 Gb/s ultimately). Broadband multiwavelength routing is implemented by means of a simple optical 2x2 switch[32], which transmits or add/drops a signal according to the control channel information it receives. The CWDM data channel format is well suited to the bus type architectures[30] common in the computer networks for which the design is addressed The architecture therefore allows for high transmission capacity optical switching and routing components to be exploited while utilising the extensive signal processing functionality of electronics.

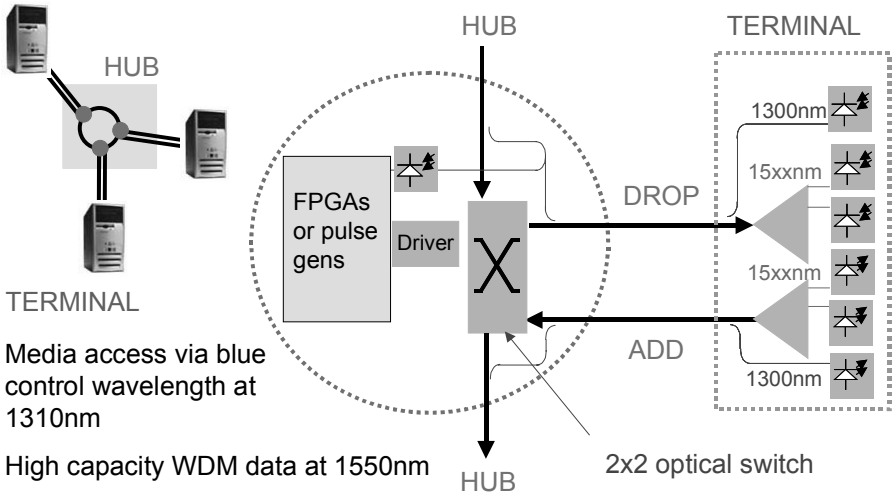


Figure 3: Schematic diagram of an implementation of the optical LAN

To provide the switching function, a special add-drop device, which has the same functionality as a crosspoint switch, has been designed and constructed using semiconductor optical amplifier (SOA) gates (figure 4). These gates are attractive for switching applications because of their high on-off ratios, wideband operation and ability to switch on fast timescales[32]. Also, on-chip device gain allows for a low cost all optical solution suitable to cascaded computing networks. The add-drop device comprises a grid of eight semiconductor optical amplifiers integrated on a single 850µm x 850µm chip. The four input and output amplifiers are waveguide splitters, which taper linearly from a single mode ridge waveguide and terminate at one of four waveguide crossings. At the waveguide crossings, four total internal reflecting (TIR) mirrors are fabricated at 45º to the waveguide (figure 5). The ridge waveguides are formed using standard laser processing and the TIR mirrors are fabricated using focussed ion beam etching. Short SOA gates for enhanced dynamic range are placed between the splitter SOAs to link the two inputs to the two outputs, allowing both switched and broadcast operation. The two opposing facets are coated to 0.5% over the C-band.

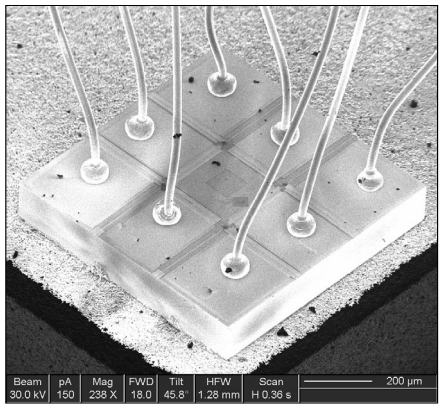


Figure 4: View of add-drop crosspoint switch showing through/add/drop configurations

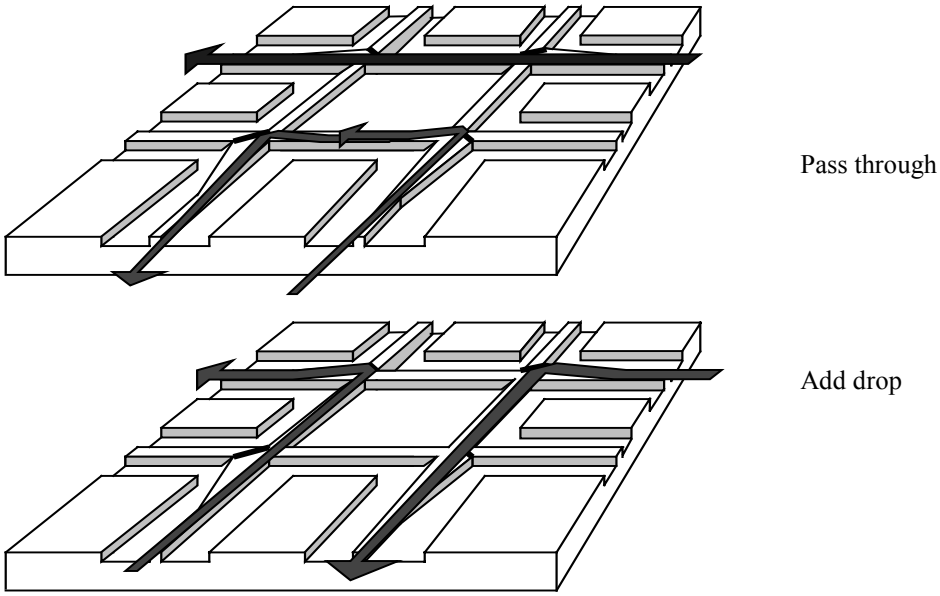


Figure 5: Schematic diagram of add-drop crosspoint switch showing through/add/drop configurations

The add-drop device performance has been assessed using WDM sources, which are commercially available DFB lasers integrated with electroabsorption modulators. Polarisation is set to TE mode and coupling into the SOA is performed with fibre lenses. The wavelengths are de-multiplexed at the receiver before detection. BER measurements are performed using an HP 2.5 Gbit/s BERT test set. The devices show strong switching performance. Under CW operation with an input power of +2.5dBm at wavelength 1550nm, an on chip optical gain of 9dB is measured, with a splitter ratio of 60:40. Switching between the add-drop modes can be achieved with a 4.5ns transition from 0-30mA on the appropriate gate. A device power consumption of 170mW is recorded for all valid operating states. Operation with less than 5 dB loss is shown from 1535nm to 1560nm (see figure 6) with a single wavelength on the pass-through port.

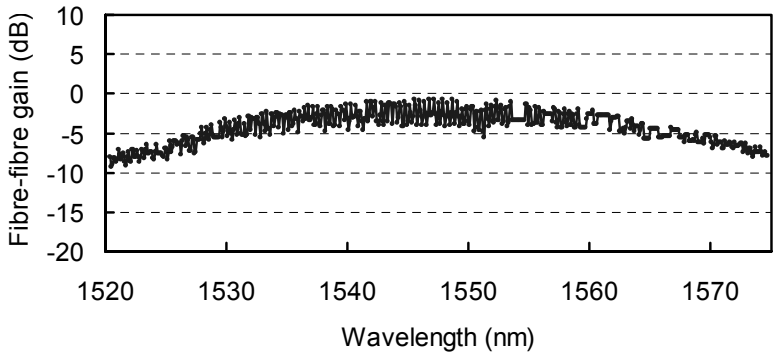


Figure 6: Wavelength dependant gain measured through a crosspoint add-drop gate

To characterise system penalty in both through and add/drop states, two wavelengths (λ1 & λ2) are applied at the pass-through port of the device while an further two wavelengths (λ3 & λ4) are applied at the add-drop ports. BER curves are characterised at 2.5Gbit/s with a 10^7-1 PRBS pattern on wavelengths 1 and 4. Measurements are performed both with and without the device present. The resulting BER curves (see figure 7) show typical BER penalties of only 0.5 dB at 10^{-9} error rate in each of the valid operating configurations. No BER floor is measured above a BER of 10^{-13} .

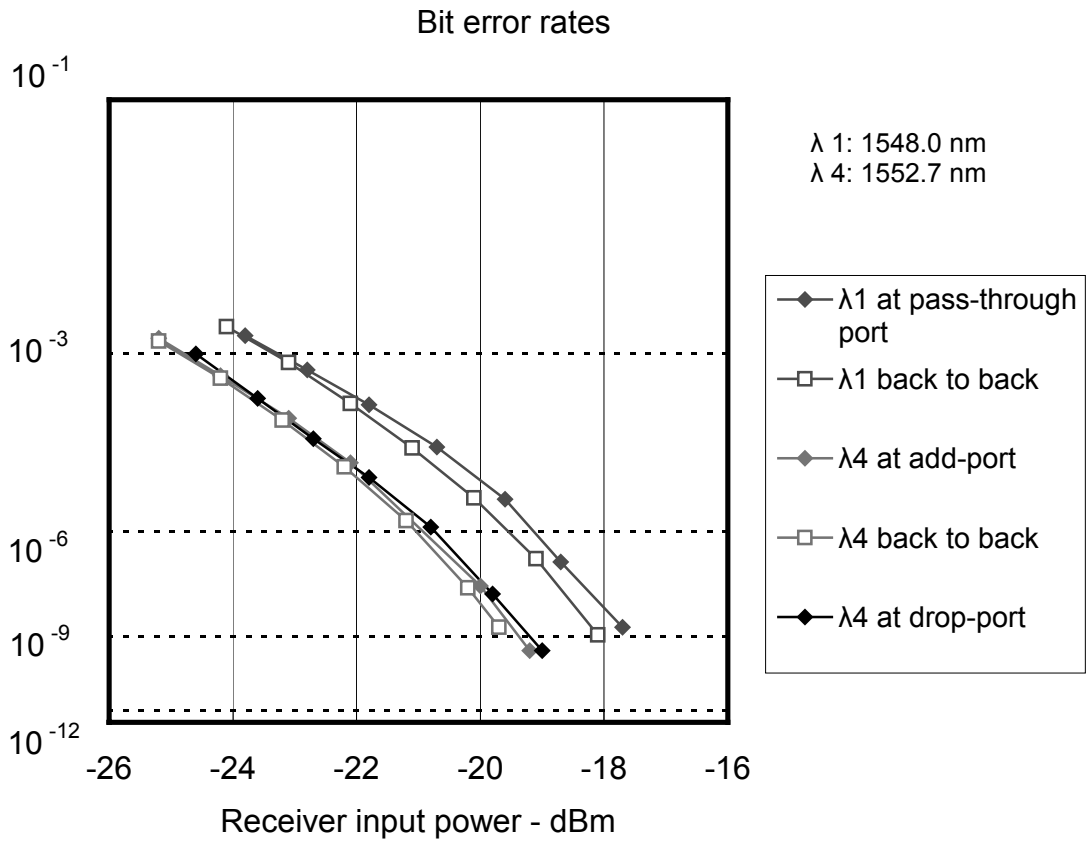


Figure 7: BER penalty curves.

This performance indicates that cascadable operation of the switch is feasible. In a system, if 12 dB is allowed for multiplexing, connector and fibre losses, a combined penalty of 4 dB is available for the switching core as proposed. Assuming linear summation of power penalties this would allow 8 devices to be cascaded. A good optical spectrum from 1535nm to 1560nm and operation of 4 simultaneous wavelengths also shows that WDM operation with at least 4 wavelengths is achievable at a data rate of 2.5Gbit/s in this scenario. A full optical LAN can therefore be envisaged using wavelength striping for enhanced overall network efficiency and flexibility, using low cost components.

4. CONCLUSIONS

Coarse WDM is beginning to be used in commercial local area networks though the 10GbE standard and in Metro and Access systems through the ITU standard. The current usage is based on 20-25nm channels to cover the temperature drift of present day DFB laser sources. The advantages of CWDM are the reduced cost due to reduction in component count and wavelength locking complexity and reduced wattage due to removal of temperature control. Using the wavelength dimension in a simple optical switching node gives the many performance advantages of higher throughput keeping the buffering and complexity in the electrical domain. It is shown that such networks can be implemented using conventional CWDM units coupled with simple SOA based optical add-drop crosspoints.

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